

DOE's EGS Program Review

Geothermal Reservoir Dynamics - TOUGHREACT

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Project Objective

Further develop and apply capabilities for reactive chemical transport modeling in enhanced geothermal systems (TOUGHREACT code).

Change: During FY06, considerable emphasis was placed on investigating the novel concept of using CO₂ as working fluid in EGS. The level of effort for TOUGHREACT-based work was reduced.



EGS Problem

- ❖ Chemical interactions between rocks and fluids have a major impact on development and operation of EGS systems.
- ❖ Water is a powerful solvent for many rock minerals. Mineral dissolution and precipitation effects are an integral and inevitable part of EGS operations. They may lead to the twin problems of creating short-circuiting pathways (dissolution) or blocking flow (precipitation), while potentially offering new approaches for stimulating and optimizing EGS systems.
- ❖ The project aids overall EGS program goals by improving understanding of chemical interactions between rocks and fluids, and by providing mathematical modeling tools that can aid in development and management of EGS systems.



Background/Approach

- ❖ TOUGHREACT adds comprehensive reactive chemical transport capabilities to TOUGH2.
- ❖ The code was released to the public in October 2004 through DOE's Energy Science and Technology Software Center (ESTSC). It is currently the second-most requested code in ESTSC's collection (after TOUGH2).
- ❖ Past EGS applications have evaluated the use of injection water chemistry to improve injection-production systems (GRC, 2004; Stanford, 2005; WGC 2005).



Results/Accomplishments

- ❖ Presented three papers at 2006 Stanford meeting. One paper submitted to 2006 GRC.
- ❖ Strong collaboration with Coso EGS project (Pete Rose).
- ❖ Further development of TOUGHREACT code.
- ❖ Held TOUGHREACT training course at LBNL in January 2006.



TOUGHREACT Training Course

- ❖ 20 participants from national laboratories, universities, and private companies (limit of our interactive training facility).
- ❖ Three-days hands-on.
- ❖ Fundamentals of reactive chemical transport processes.
- ❖ Emphasis on practical problem solving.
- ❖ Another course planned for October 2006.

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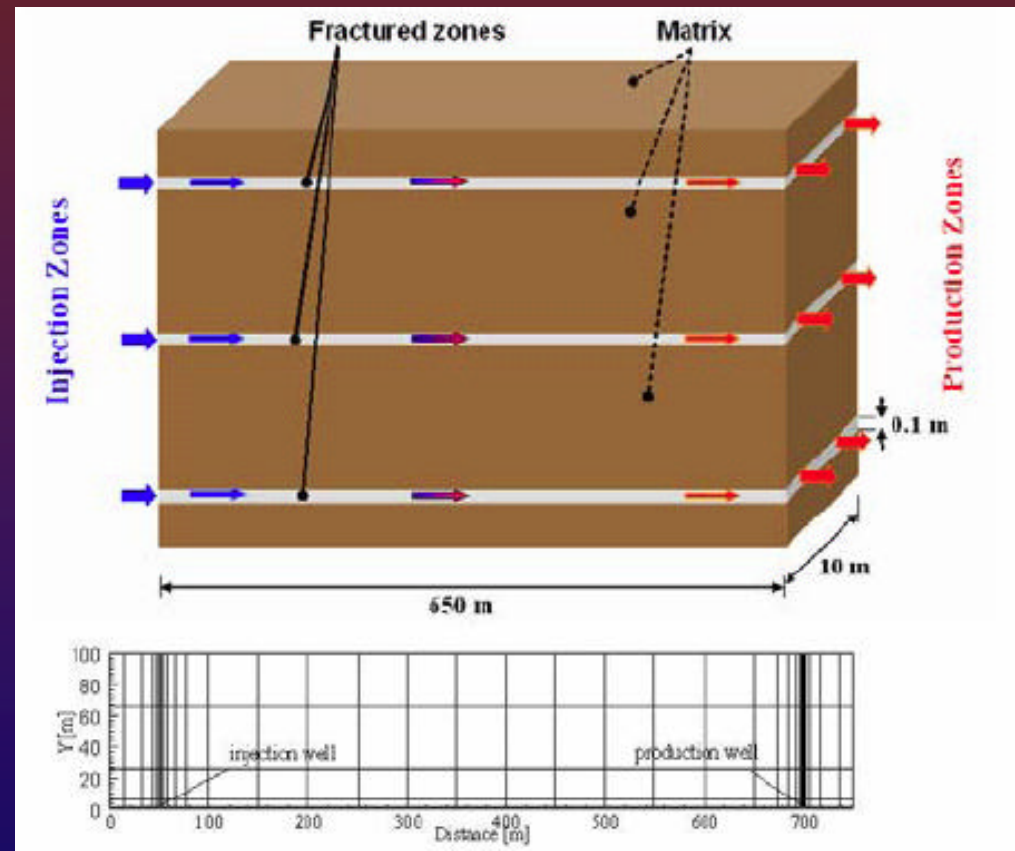


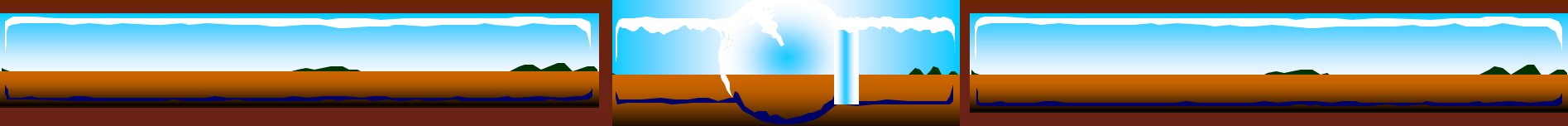
Kinetics for Homogeneous Reactions

- ❖ Many aqueous reactions are very slow and kinetically-controlled. Examples are redox reactions such as
$$\text{Fe}^{+3} <---> \text{Fe}^{+2}, \text{CO}_{2,\text{aq}} <---> \text{CH}_{4,\text{aq}}, \text{SO}_4^{-2} <---> \text{HS}^-$$
- ❖ The local equilibrium approximation (LEA) gives an inaccurate description of these reactions, and it leads to great numerical difficulties.
- ❖ A general kinetic rate law for homogeneous reactions has been implemented in TOUGHREACT. In addition to redox, this can also describe microbiological processes.
- ❖ Paper presented at TOUGH Symposium, May 2006.

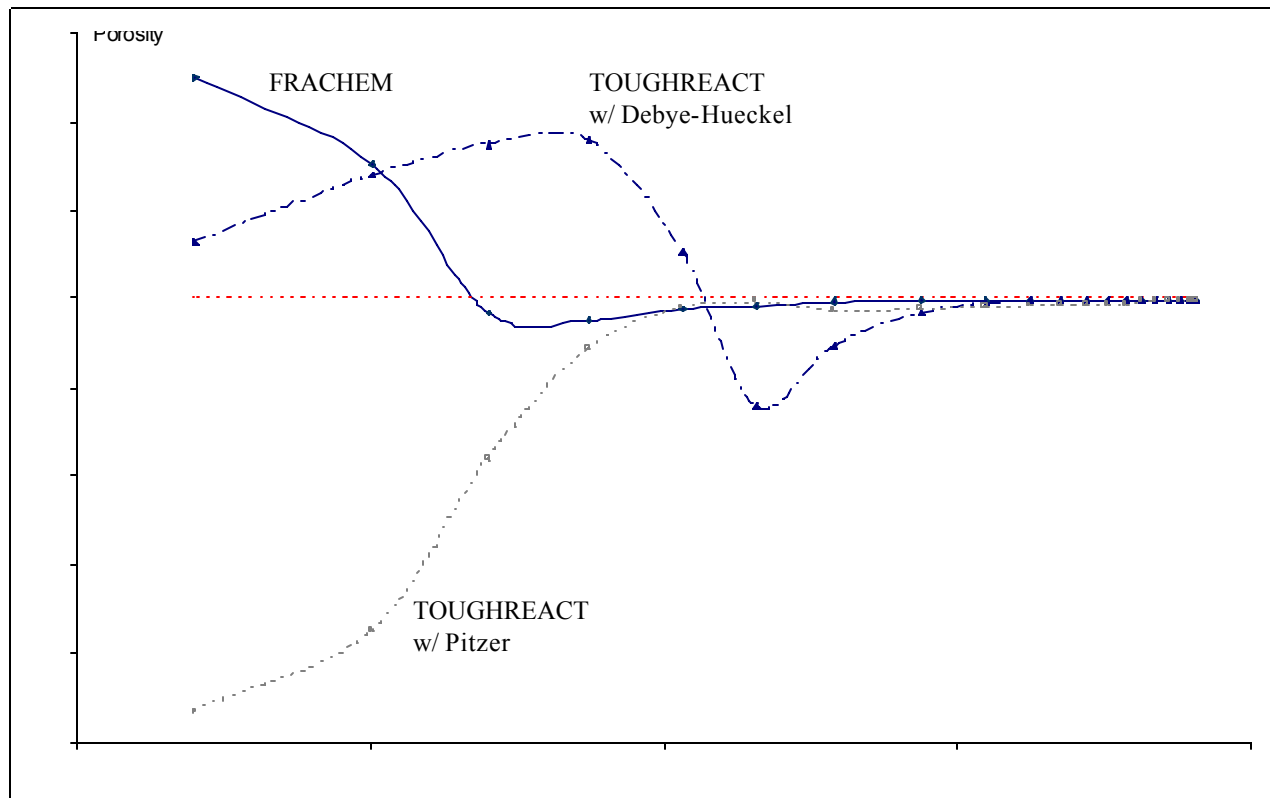
Implementation of Pitzer Model into TOUGHREACT

- Many EGS applications involve highly saline fluids.
- Implemented Pitzer ion activity model into TOUGHREACT and performed comparisons with FRACHEM code.
- Used simplified model of EGS system, patterned after Soultz, France. $T = 200\text{ }^{\circ}\text{C}$, $\text{TDS} = 100,000\text{ ppm}$.
- Paper presented at 2006 Stanford meeting (André et al.).



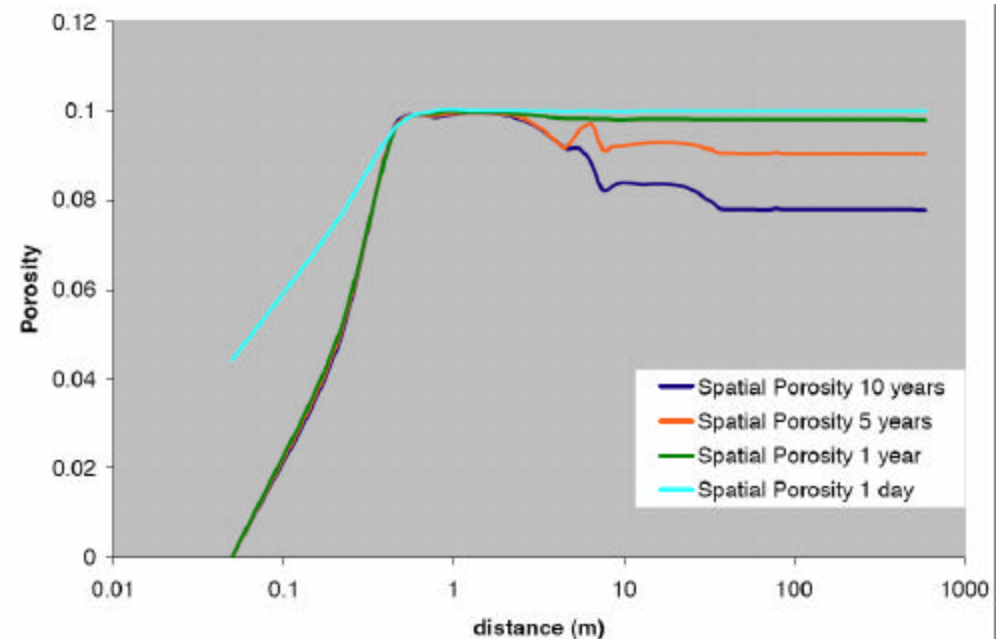
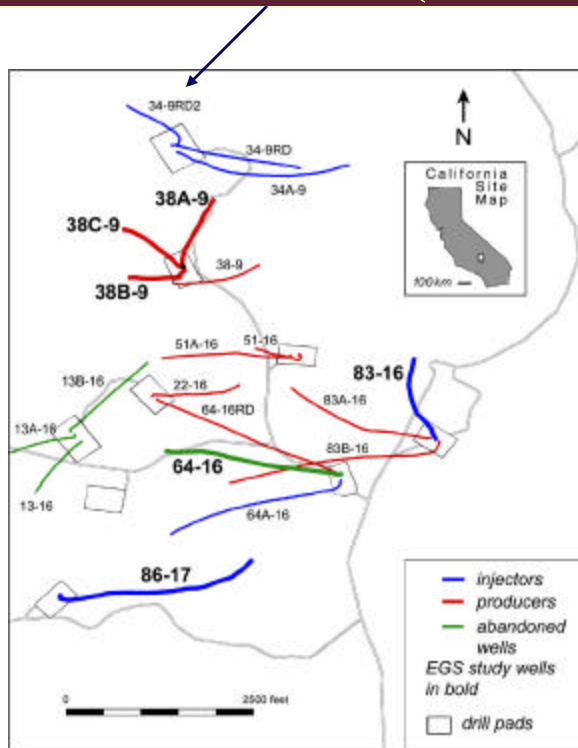


Code Intercomparison: TOUGHREACT - FRACHEM (André et al., Stanford 2006)



- Severe discrepancies between the codes were subsequently traced to errors in thermodynamic data and have been resolved.
- Implementation of Pitzer ion activity model in TOUGHREACT was completed.

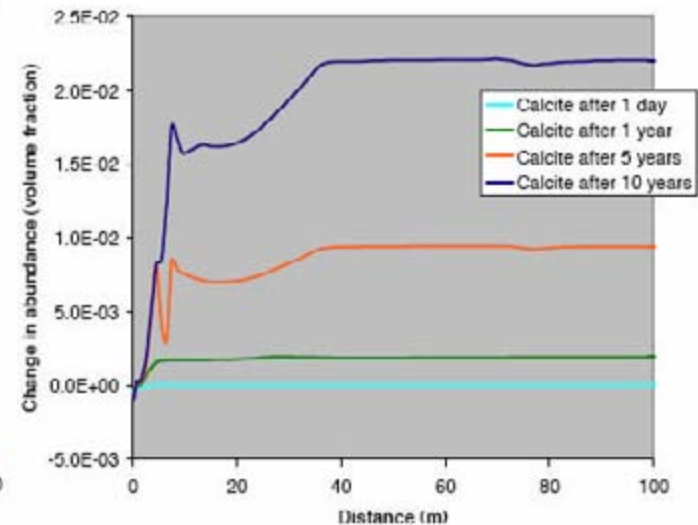
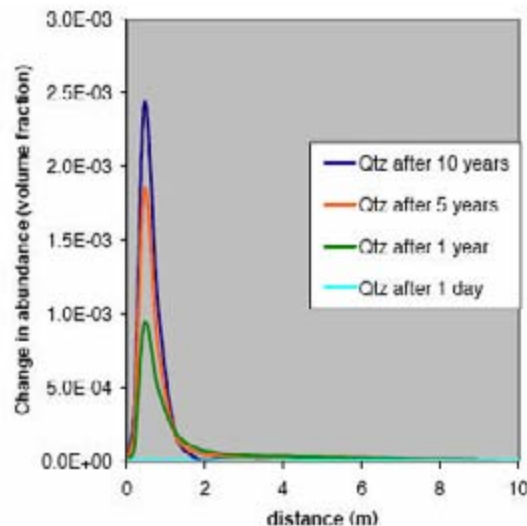
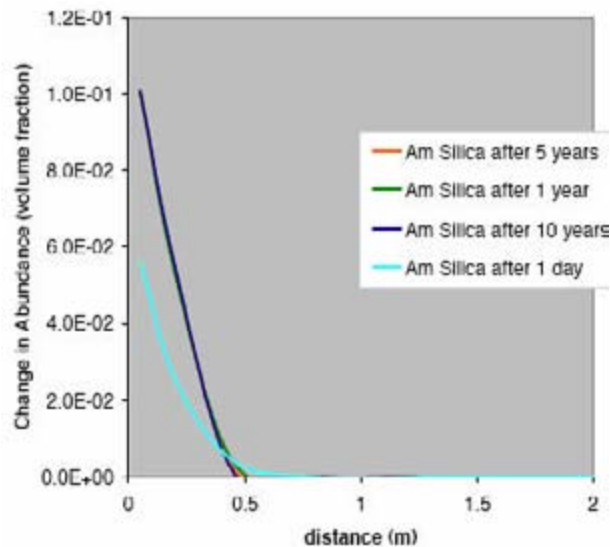
REACTIVE CHEMICAL FLOW MODELING APPLIED TO INJECTION IN THE COSO EGS EXPERIMENT (Kovac et al., Stanford 2006)



Simulated porosity change



REACTIVE CHEMICAL FLOW MODELING APPLIED TO INJECTION IN THE COSO EGS EXPERIMENT (Kovac et al., Stanford 2006)





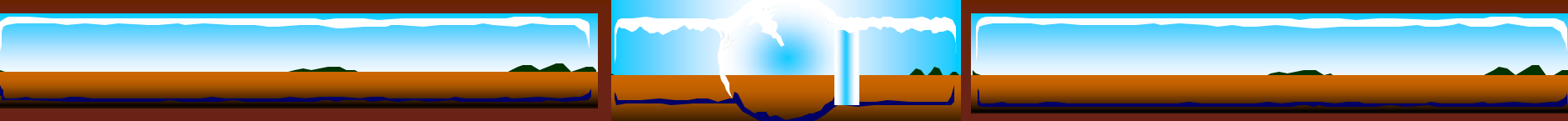
MODELING THE GEOCHEMICAL EFFECTS OF INJECTION AT COSO GEOTHERMAL FIELD (McLin et al., Stanford 2006)

Mineral	Volume Fraction of Solid Rock			
	1710 m: Granodiorite-hosted		878 m: Diorite-hosted	
	Average Weakly- Altered Granodiorite	Fracture	Average Weakly- Altered Diorite	Fracture
Quartz	0.34	.05	.135	
Potassium Feldspar				
	0.17		.045	
Chlorite	0.02	.01	.01	
Illite	0.03		0.00	
Calcite	0.02	.04	.025	.009
Anorthite	0.33		.038	
Annite	0.06		0.15	

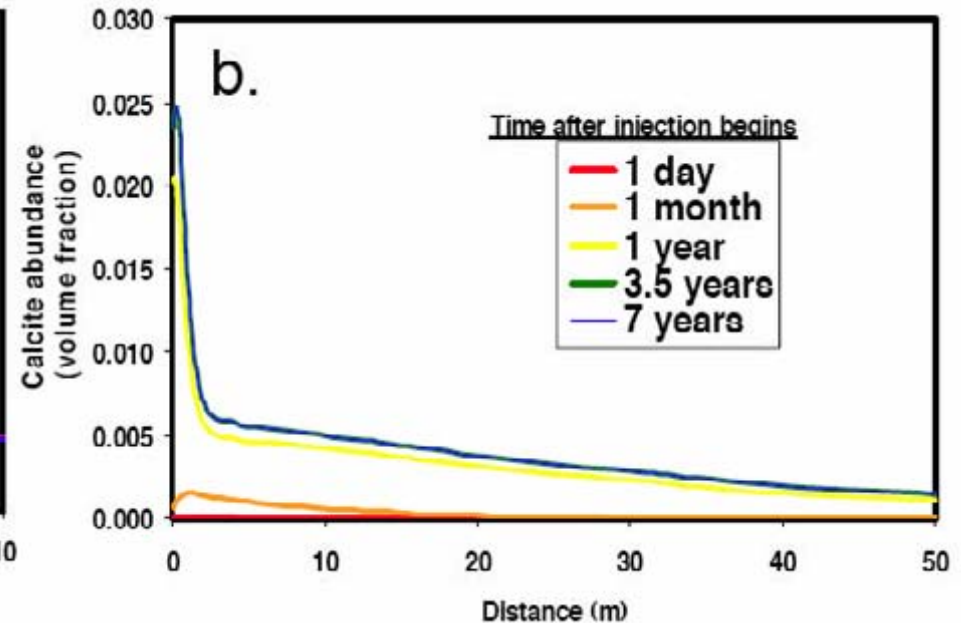
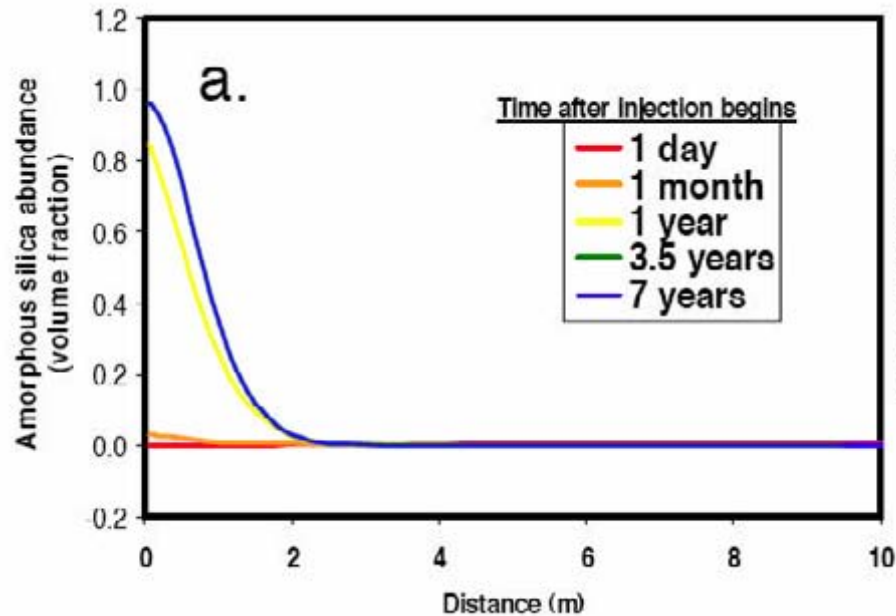
Mineral composition

Chemical Component	Reservoir (Mol/kg)	Injection (Mol/kg)
SiO ₂	1.30E-2	9.96E-03
B(OH) ₃	8.42E-3	1.01E-02
Na ⁺	9.50E-2	1.46E-01
K ⁺	1.20E-2	1.42E-02
Li ⁺	2.45E-3	4.44E-03
Ca ²⁺	9.55E-4	1.07E-03
Mg ²⁺	4.12E-6	2.22E-2
Sr ²⁺	3.60E-5	5.00E-2
Cl ⁻	1.10E-1	1.60E-01
F ⁻	1.47E-4	1.15E-04
HCO ₃ ⁻	1.10E-3	2.48E-03
SO ₄ ⁻	3.12E-4	6.97E-04
HS ⁻	3.02E-5	
CH ₄	6.25E-10	
pH	6.84	6.47
As		1.16E-04

Water composition



MODELING THE GEOCHEMICAL EFFECTS OF INJECTION AT COSO GEOTHERMAL FIELD (McLin et al., Stanford 2006)





Conclusion

- ❖ Will the project objective be achieved by the project completion date?
 - ❖ Yes – transferred new simulation technology to the technical community; enhanced process modeling capabilities; demonstrated techniques for chemical stimulation and control of EGS systems.
 - ❖ No – applications were more limited in scope than anticipated (e.g., no mechanically-coupled analyses were pursued), due to shift of effort towards EGS with CO₂.